ADAPTING METEOROLOGICAL APPROACHES IN IRRIGATION SCHEDULING TO HIGH RAINFALL AREAS[1/]

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Introduction

The irrigation scheduling program developed by Jensen, et al. (7)[3/] and used by the Bureau of Reclamation, irrigation districts, and several private consultants has been widely accepted by the irrigators subscribing to the scheduling service. The program, summarized in the previous paper, forecasts the next date of irrigation by maintaining a water budget and estimating the number of days until the soil water depletion approaches an optimum value. The depletion or evapotranspiration rate used for estimating the next irrigation is a 6-day average occurring at the time of forecasting. The irrigation-scheduling program accounts for the precipitation that occurs before the date of forecast but assumes no additional rainfall before the date of irrigation.

Most of the areas in which the irrigation-scheduling program has been used are located in the arid and semiarid Western United States. In these areas, limited rainfall has little effect on the predicted date of irrigation. Also, 6-day average evapotranspiration is more uniform from week to week than in sub-humid regions. Most of the variability in consecutive estimates of the date of irrigation is caused by the differences between the estimated evapotranspiration and that actually occurring in the forecast period. Adapting the irrigation-scheduling program to sub-humid and humid regions may require a more stable forecast of evapotranspiration and the inclusion of rainfall probability. This paper describes procedures for including the precipitation probability in the program for scheduling irrigations, and the effects of using long-time average evapotranspiration rates for the forecasts.

Forecasting with $\overline{E}_{tp}(t)$

An estimate of expected crop E_t throughout the season was added to provide a more realistic forecast during the early part of the growing season when the E_t is changing rapidly. Forecasting with precipitation probabilities will increase the irrigation interval, requiring an accurate estimate of the expected crop E_t. A 6-day average E_t rate may be satisfactory for forecasting 1 or 2

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weeks but may give erratic forecasts for longer periods. The previous paper at this symposium presented a simple procedure for providing a more stable mean E_t. This procedure assumes that the mean potential E_t distribution, $\overline{E}_{tp}(t)$, can be represented by a "normal" distribution function

$$\overline{E}_{tp}(t) = E'_{tp} \exp - \left\{ \left[\frac{t-t'}{\Delta t} \right]^2 \right\} \qquad [1]$$

where $\overline{E}_{tp}(t)$ = the mean E_{tp} expected at a given date t (in calendar days),

t' = the calendar day when the maximum mean potential, E'_{tp}, occurs (about July 15 in the Northern hemisphere),

and Δt = the days before and after t' when $\overline{E}_{tp}(t) = 0.37\ E'_{tp}$.

The procedure for estimating the necessary parameters is illustrated for Akron, Colorado (Figure 1).

Simulation Test Data

Akron, Colorado was chosen for illustrating the effect of including $\overline{E}_{tp}(t)$ and precipitation probabilities in irrigation scheduling because of available climatic data (1968-69) and precipitation probabilities. The average annual precipitation is 16.75 inches. Climatic data including daily solar radiation, daily wind run, maximum and minimum air temperatures, humidity and rainfall were used in the modified Penman equation (8) to estimate the potential evapotranspiration and compute the water budget. The same climatic data were used to test the applicability of the water budget portion of the Jensen, et al. (7) irrigation-scheduling program to dryland agriculture. Excellent results were obtained in estimating the water budget for dryland grain sorghum (6). The program should, therefore, simulate an irrigation regime using the same data.

The soil at Akron, Colorado has an available-water-holding capacity of 2 inches per foot of depth. An optimum depletion of 3.5 inches was assumed for the irrigated corn crop used to simulate irrigation scheduling.

Scheduling with $\overline{E}_{tp}(t)$

The 1968 season was simulated with irrigations applied each time the soil deficit exceeded 3.5 inches. Forecasts of irrigation dates were made on 5-day intervals using the 6-day average E_t and average E_t derived from $\overline{E}_{tp}(t)$ (Figure 2). Considerably more consistency in forecasting irrigation dates occurred when using $\overline{E}_{tp}(t)$.

Precipitation Probabilities

Published precipitation probabilities can be included in an irrigation scheduling program. An incomplete gamma function has been used to estimate the probability of receiving at least a given amount in a 1-, 2-, or 3-week period (1, 2, 3, 4, 5, 9, 10, 11, 12). This procedure is useful since it provides the amount of precipitation expected in a specified time period. The assumption is made that interpolations from published probability tables will improve the accuracy of predicted irrigation dates.

In using the precipitation probability for scheduling irrigations, it is convenient to express a daily amount at a given probability level. The product of daily probability and the time period provides the total probable amount. A computer program was written to linearly interpolate the expected amount of precipitation at a given probability level from 1-, 2-, and 3-week precipitation probability tables. Figure 3 shows the average daily precipitation amounts at the 50 percent probability level for Akron, Colorado. Approximately a 0.01-inch/day difference exists between the 1- and 2-week curves with very little difference between the 2- and 3-week curves. The 75 percent probability curve for the 2-week period is also included. The 2-week probability curves for Columbus, Kansas, and Storrs, Connecticut, have higher precipitation amounts.

The precipitation probability was estimated with a third-order polynomial for the 2-week curves for Akron (Figure 3). For stations such as Columbus, Kansas, and Storrs, Connecticut, it would be better to use a fourth-order polynomial (Figure 3). The change between the 1- and 2-week curves was approximated by an exponential equation

$$\tau = 14e^{75p} \qquad [2]$$

where τ = time in days, p = precipitation amount (inches), and e = base of Naperian logarithm. This relation appears to adequately describe the precipitation probability for periods shorter than 2 weeks. Any time period exceeding 2 weeks was assumed to have a daily probability equal to that of the 2-week curve.

Scheduling with Precipitation Probabilities

The irrigation scheduling program was modified to include an estimated irrigation date with a given probability of rainfall. The procedure first estimates the irrigation date assuming no rainfall and then calculates the expected precipitation in this time period. The anticipated precipitation (assumed 100 percent effective) extends the number of days to the next irrigation. An iteration scheme was included to increase the irrigation interval until the forecasted irrigation-date increase was less than 1 day.

The simulation results for scheduling the irrigations for the 1968 and 1969 seasons are shown in Figures 4A and B, respectively. Forecasts with and without probable amounts of precipitation provide an envelope for the simulated irrigation date, especially early in the season where the expected precipitation is higher.

Scheduling Frequent Irrigations

Irrigation, particularly sprinkler irrigation, is increasing in the sub-humid and humid regions. Many of the newer sprinkler irrigation systems are readily adapted to light and frequent irrigations. With this capability, it would be advantageous to schedule the irrigation date and amount to always leave some water-holding capacity for the rain that might occur following an irrigation.

Two irrigated corn seasons at Akron were simulated with 1-inch irrigations applied when the soil water was depleted 2 inches, thereby allowing enough reserve root zone capacity to store a 1-inch rain. The first irrigation was required a week earlier with the smaller irrigation depth, but the convergence of forecast and simulated irrigation dates was similar to those in Figures 4A and B. The total seasonal amount of irrigation water was approximately the same, whether the root zone was filled or left partially depleted after each irrigation.

The simulation program assumed that any soil water in excess of field capacity was lost as deep percolation. Only 0.5 inch seasonal deep percolation was calculated for the 1-inch irrigation regime as compared to 1.25 inches for the 3.5-inch regime. As rainfall increases, greater reduction in deep percolation would be expected. The reduction in deep percolation not only represents a direct saving of water but also may decrease the amount of soluble plant nutrients leached below the root zone.

Discussion

The inclusion of precipitation probabilities required a probability estimate and an estimate of expected $\bar{E}_{tp}(t)$ throughout the season. The first irrigations for both 1968 and 1969 illustrate the advantage of including precipitation probabilities in the scheduling of irrigations. In 1968, the forecasts made assuming no precipitation were much closer to the simulated irrigation date, but the opposite occurred in 1969.

After the first irrigation at Akron, Colorado, only small differences occurred between forecast dates with or without probable precipitation amounts. Two principal factors reduced this difference: [1] The number of days between irrigations was less and therefore less precipitation was expected; and [2] E_t increased and became much larger relative to the amount of daily probable precipitation.

The estimated number of days to irrigation was increased by approximately 80 percent at the beginning of the season (May 5) for Akron, Colorado when precipitation probability was added. By June 1st the estimated irrigation date was extended only 40 percent and by July 1st, only 20 percent. The decision for including precipitation probabilities in irrigation-scheduling can be based on the ratio of the probable precipitation to the estimated crop E_t for a comparable time period.

At Akron, when the ratio is less than 0.5, the forecast with probable precipitation has very little effect. The ratio at Akron equals 0.5 near the time of the first irrigation. The increasing magnitude of $\overline{E}_{tp}(t)$ corresponds with the decreasing magnitude of probable precipitation amount, causing the ratio to change rapidly. The ratio of probable precipitation to estimated crop E_t at which precipitation probabilities should be included may be quite different at other locations.

It could be concluded that in an area such as Akron, Colorado, irrigation-scheduling probably would not require the additional complexity of including precipitation probabilities, since only the first irrigation date would be significantly affected. In areas such as southeast Kansas and Connecticut where the 2-week daily probable rainfall ranges from 0.085 to 0.14 inch/day (Figure 3), the precipitation probability would significantly affect the irrigation scheduling for most of the growing season. Use of $\overline{E}_{tp}(t)$ would probably result in more consistent forecast dates in all areas except when scheduling frequent and light irrigations (i.e., shallow rooted sensitive crops).

Summary

A computer program has been written to include precipitation probabilities in the Jensen, et al. (7) program for scheduling irrigations. The precipitation probabilities during the season are expressed by a polynomial equation and an exponential equation is used to make the necessary adjustments in a daily rate for different forecast time periods. $\overline{E}_{tp}(t)$ was added for forecasting when the days to irrigation were greater than 2 weeks. Average daily potential E_t for the season was represented by a "normal" distribution equation. The program for scheduling irrigations retains its simplicity for the user when representing the precipitation probability and $\overline{E}_{tp}(t)$ by simple equations. The subroutine for including the precipitation probabilities and programs for curves to fit precipitation probabilities are available upon request from the authors.

Literature Cited

1. Bark, L. Dean. 1963. Chances for precipitation in Kansas. Agricultural Experiment Station, Kansas State University, Manhattan, Kansas. Bulletin 461.

2. Colville, W. L. and R. E. Meyers. 1965. Nebraska's precipitation, its patterns and probabilities. Misc. Pub. 10. Nebraska Agricultural Experiment Station, Lincoln, Nebraska.

3. Dethier, B. E. and J. K. McGuire. 1961. The climate of the Northeast; Probability of selected weekly precipitation amounts in the Northeast region of the U. S. Cornell Univ. Agric. Exp. Sta. Agronomy Mimeo 61-4.

4. Friedman, D. G. and B. E. Janes. 1957. Estimation of rainfall probabilities. Conn. Agri. Exp. Sta. Bul. 332.

5. Gifford, R. O., G. L. Ashcroft and M. D. Magnuson. 1967. Probability of selected precipitation amounts in the Western region of the U. S. Western Regional Research Publication T-8. Agricultural Experiment Station, Univ. of Nevada.

6. Heermann, D. F. and H. R. Gardner. 1970. Evapotranspiration model for dryland crops for the Great Plains. Proceedings of Great Plains ET Seminar, Bushland, Texas.

7. Jensen, M. E., J. L. Wright, and B. J. Pratt. Estimating soil moisture depletion from climate, crop and soil data. Trans. Am. Soc. Agr. Eng. (in press). Paper No. 69-641, ASAE Winter Meeting, December 1969.

8. Penman, H. L. 1963. Vegetation and hydrology. Tech. Communication No. 53, Commonwealth Bureau of Soils, Harpenden, England, 125p.

9. Rosenberg, Norman J. 1963. Climatic atlas of irrigated regions in Nebraska. No. 1. The climate of the Central Platte Valley. Misc. Pub. 9. Nebraska Agricultural Experiment Station, Lincoln, Nebraska.

10. Shaw, R. H., G. L. Barger, and R. F. Dale. 1960. Precipitation probabilities in the North Central states. Univ. of Missouri Bul. 753.

11. Thom, H. C. S. 1958. A note on the Gamma distribution. Month. Wea. Rev. 86, 117-122.

12. Work Group on Hydrologic Analyses and Projections Standing Committee on Comprehensive Basin Planning. Missouri Basin Inter-Agency Committee. The Missouri River Basin. 1967. Precipitation probability levels and durations of 1-, 2-, 4-, and 8-weeks.

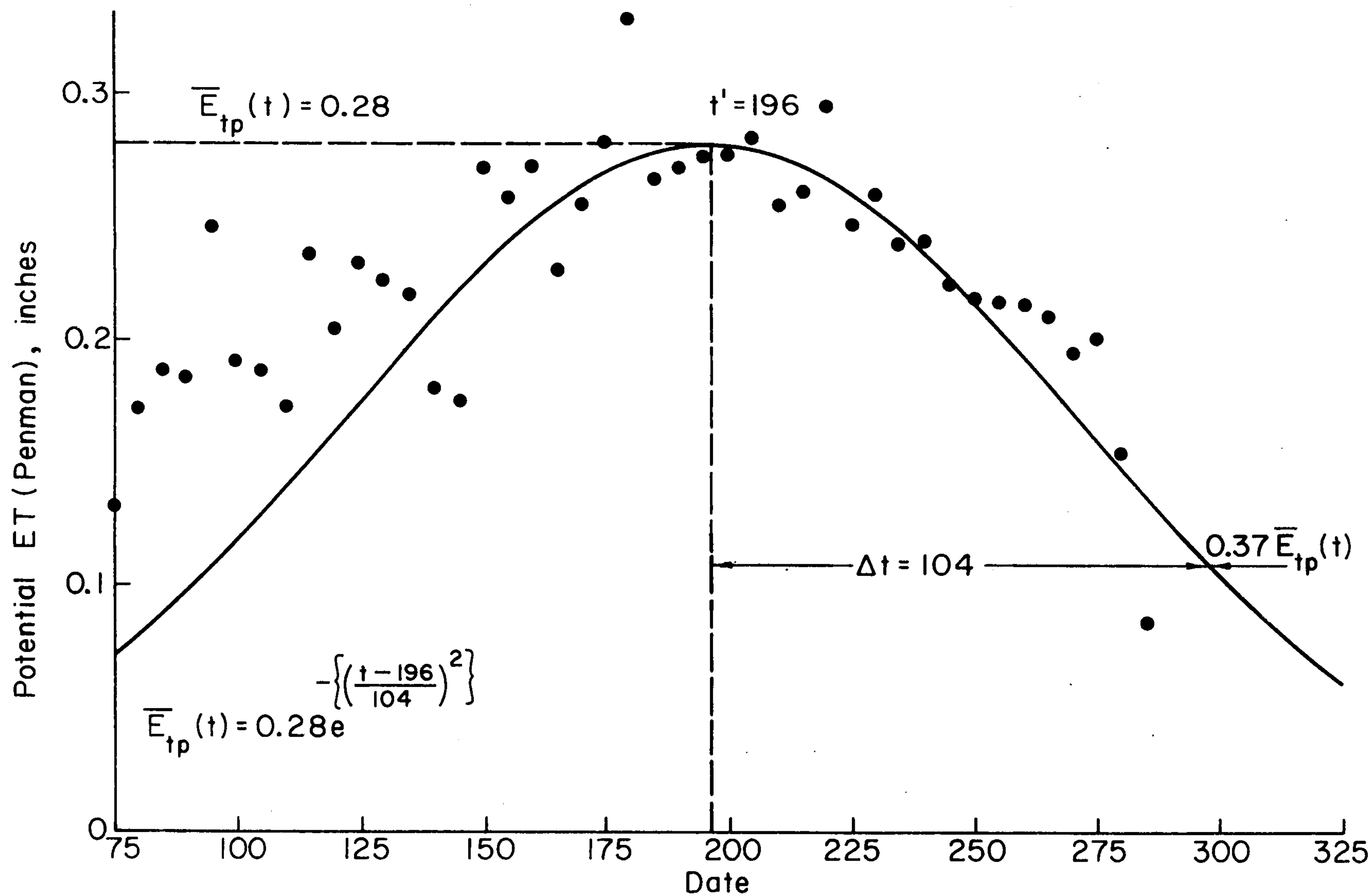

Figure 1. Graphical procedure for determining the "normal" distribution function for $\overline{E}_{tp}(t)$ at Akron, Colorado.

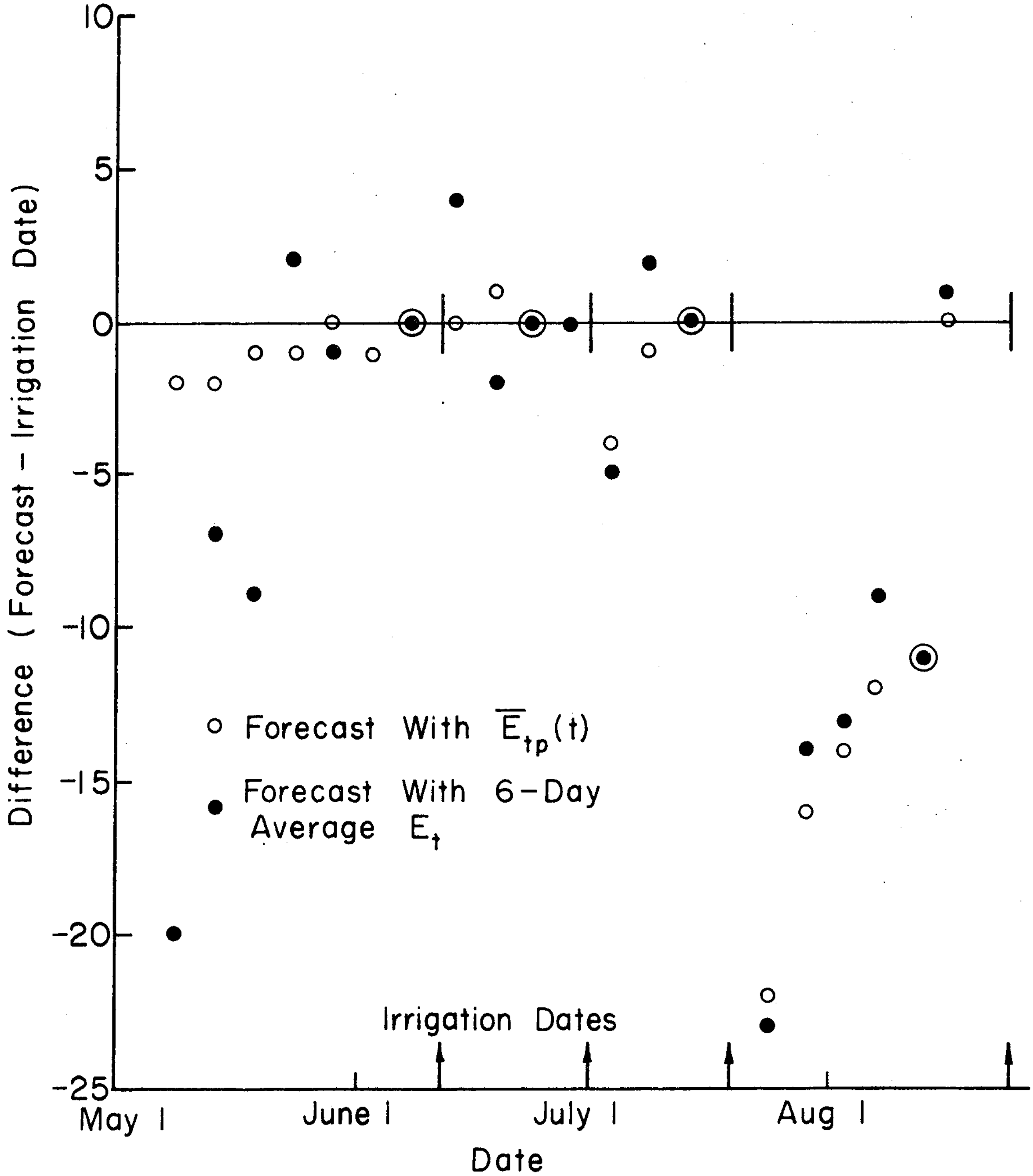

Figure 2. Forecast minus irrigation date versus forecast date for Akron, Colorado (1968) with 6-day average E_t and $\overline{E}_{tp}(t)$.

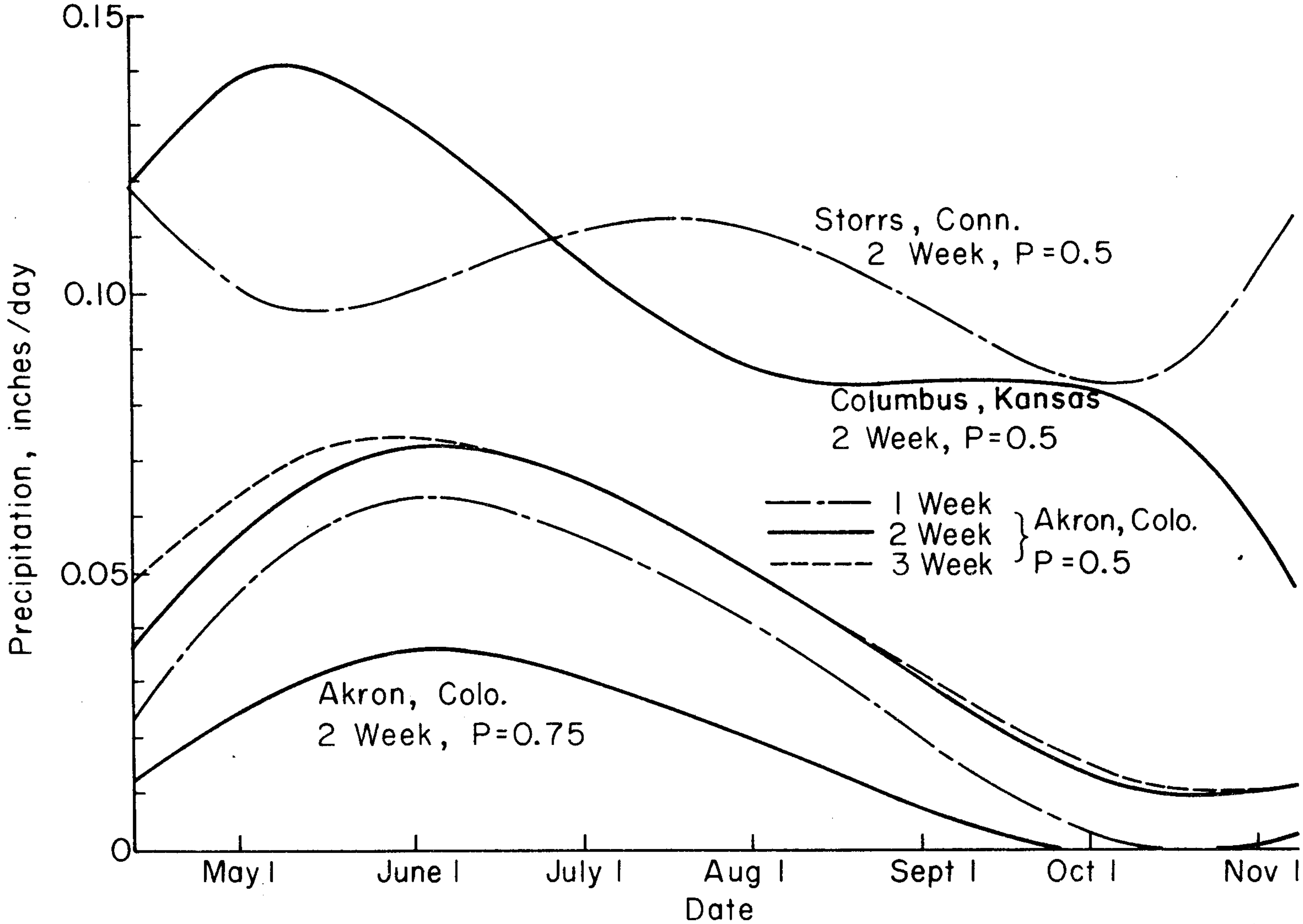

Figure 3. Daily precipitation probabilities from 1-, 2-, 3-week tables for Akron, Colorado, Columbus, Kansas and Storrs, Connecticut.

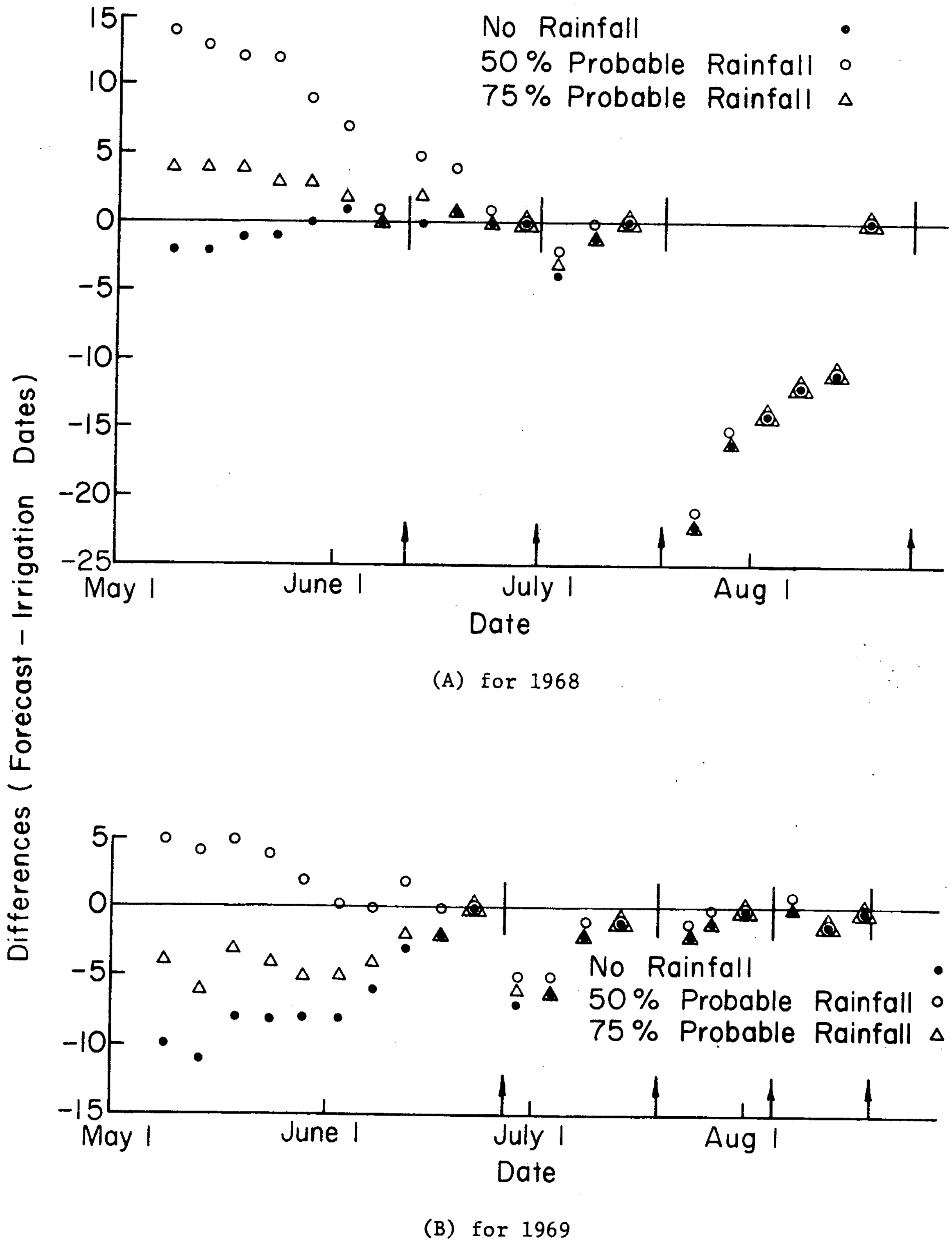

Figure 4. Forecast minus irrigation date versus forecast date for Akron, Colorado with probable precipitation.